DOCUMENT RESUME

ED 244 814 SE 044 539

AUTHOR Avons, S. E.; And Others
TITLE Microprocessors in Education Research Project. Final Report.
INSTITUTION Manchester Univ., (England). Dept. of Psychology and Education.
SPONS AGENCY Leverhulme Trust, London (England).
PUB DATE Sep 83
NOTE 30p.
PUB TYPE Reports - Research/Technical (143)

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS Area; *Comprehension; *Computer Oriented Programs; *Computer Simulation; Educational Research; Elementary Education; *Elementary School Mathematics; *Elementary School Science; Graphs; Mathematics Instruction; *Microcomputers; Science Instruction
IDENTIFIERS Information Integration Theory; *Mathematics Education Research; Science Education Research

ABSTRACT

This 3-year research project, centered on the cognitive psychology of child-computer interaction, focused on the use of microcomputers for teaching specific topics in mathematics and science. In particular, issues arising from the use of computer-based simulations to promote learning (including the nature of the information displayed, the degree of interaction between child and machine, and the nature of the student-machine interface) were examined. Specific areas investigated were comprehension of Cartesian graphs, the ability to understand the concept of area and its relationship to the estimation of rectangular area, and the perceptual-motor limitations of young children interacting with computerized displays using a light pen (comparing 5- to 11-year-olds). This report provides: (1) a summary and overview of the project; (2) an outline of progress made; (3) a discussion of methodology, results, and educational implications of these results; and (4) recommendations related to difficulties in planning and undertaking this kind of educational research. In addition, details of the project management and lists of internal project reports and publications are included. One finding reported is that, contrary to prevailing views, allowing children interactive control of animated displays does not lead to detectable changes in conceptual understanding. (JN)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED244814

MICROPROCESSORS IN EDUCATION RESEARCH PROJECT

(Funded by the Leverhulme Trust)

U.S. DEPARTMENT OF EDUCATION
NATIONAL INSTITUTE OF EDUCATION
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)
This document has been reproduced as received from the person or organization originating it.
Minor changes have been made to improve reproduction quality.
Points of view or opinions stated in this document do not necessarily represent official NIE position or policy.

FINAL REPORT

S.E. AVONS

M.C. BEVERIDGE

G.J.HITCH

Departments of Psychology and Education

University of Manchester

September, 1983

"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY
M.C. Beveridge
TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

SE044539

INTRODUCTION.

Outline

This final report, prepared for the Leverhulme trust has two purposes. The first is to provide a summary and overview of three years' experimental work, outlining progress over that period and indicating the educational implications of our results. Secondly, we wish to make some recommendations based on our experiences which may be useful to others; these are concerned with the difficulties of planning and undertaking educational research of this kind.

In addition this report gives details of the management of the project, a complete list of the internal reports issued by the project team and a list of publications based on project work.

Project management

The microprocessors in Education Research Project was set up jointly by three academic staff members at Manchester University: Dr. M. C. Beveridge and Dr. A. T. Hickman (Department of Education) and Dr. G. J. Hitch (Department of Psychology). Their proposal concerned the use of microcomputers for teaching specific topics in mathematics and science and centred on the cognitive psychology of child-computer interaction (the "pupil-machine encounter"). It was proposed to examine issues arising from the use of computer-based simulations to promote learning, including the nature of the information displayed, the degree of interaction between child and machine and the nature of the pupil-machine interface. We anticipated drawing general conclusions about the cognitive processes involved in this type of learning and the factors likely to influence the effectiveness of microcomputer-based instruction.

The proposal recommended the appointment of a full-time Research Associate to administer and supervise the experimental work. Dr. S. E. Avons was appointed at the start of the project. The Leverhulme Trust provided the financial support, which provided for the Research Associate's salary, part-time secretarial help and incidental expenses such as conferences and travel (Footnote 1).

The project began in October, 1980, and was scheduled to run for three years. In June, 1982 Dr. Hickman took early retirement and his services were lost to the project. On July 1st, 1983, Dr. Avons left the Unversity of Manchester to take up an academic appointment elsewhere. As the project was due to terminate in the following October, there was insufficient time to make another appointment. Experimental work on the project ceased in June, 1983, and the remaining weeks were devoted to preparing the last internal reports and publications.

SUMMARY OF RESEARCH

(a) Overview.

Given that we intended to conduct a tightly controlled experimental programme, our remit although limited was still too broad. We therefore had to be selective. The "pupil-machine encounter" referred to in the proposal could be construed as embracing children's conceptions of microcomputers, or effects of microcomputers on classroom discourse, as well as human factors, cognitive ergonomics and areas related to the cognitive psychology of instruction. Our work makes contact with several of these, but in its main thrust is concerned with the cognitive psychology of instruction, particularly with children's interpretations of diagrams (Footnote 2)

There were three reasons behind this approach. The first was the belief in the importance of cognitive psychology as both a theoretical approach and a set of investigative methods, sufficiently powerful for understanding and resolving problems of learning. The currency of cognitive psychology is the way information and knowledge are internally represented and transformed. Many educational problems reside here. Within the fields to which intensive cognitive research has been addressed, most notably reading, spelling and mental arithmetic, considerable progress has been made (Lesgold & Perfetti, 1981; Frith, 1980; Carpenter, Moser & Romberg, 1982). A second reason for our choice of direction was that we wished to tackle fundamental problems, not specific to one generation of educational aids. Knowing about the comprehension and utilisation of diagrams may be transferred to any subsequent type of visual aid which has the power of a microcomputer. Hence the benefits of this kind of research would not be ephemeral. Thirdly, the microcomputer offers some unique capabilities as an educational aid. Amongst these are its real-time and interactive capabilities. Real-time control offers the possibility of animated displays, in which changes are correlated in time as well as in space. Interaction allows a child to explore a domain more fully and to observe more or less immediately the consequences of his own actions. We thought it important to investigate these capabilities, since these features are likely to extend beyond the present generation of educational aids.

Our next major decision concerned choice of suitable educational domains within which to work. Physics was instantly appealing, on the basis of its importance as a discipline, its relevance to everyday life, and its concern with concrete variables and dynamic changes. Our work falls within two broad areas of concern: (i) Comprehension of Cartesian graphs and (ii) The ability to understand the concept of area and its relationship to the estimation of rectangular area. We also undertook an ergonomic study into the perceptual-motor limitations of young children interacting with computerised displays using a light pen. These will be considered in turn.

(b) Graphical Comprehension.

Our first studies (Internal Reports Nos. 1 & 2, Publication No. 1) looked at the potential of animated displays for teaching children the nature of journey graphs. A number of influences directed us to this problem. Local educational advisers informed us that the lack of temporal information in conventional diagrams was a great disadvantage when trying to teach about dynamic changes. We were able to draw on two recent accounts of the conceptual difficulties experienced by children in journey graph comprehension (Janvier, 1978; Hart, 1982). Our interest was also aroused by computer software being developed for use in teaching schoolchildren to interpret graphs, such as the EUREKA program (Phillips, 1982).

We decided therefore to construct a microcomputer-based display of a concurrent simulation and graph. The simulation consisted of an animated picture of a motor car moving along a road, and alongside this a Cartesian graph describing its motion was simultaneously drawn in real time. Children were shown a number of such displays, and were then tested for their knowledge of the representation of time, distance and speed relations contained in journey graphs. We were interested in the ease of perceiving the crucial temporal and spatial correspondences between the simulation and the graph and how this is affected by allowing the child active control of the simulation.

We presented this teaching situation to primary school children with no previous experience of journey graphs. To investigate the above questions we studied the influence of several variables. Experiment one manipulated the spatial correspondence between the animated simulation and the graph, and in addition, provision of interactive control of the simulation. Figure 1 illustrates the first of these manipulations. A second experiment was performed to resolve some unanswered questions arising from the first, and contrasted reliance on purely visual information with the use of verbal descriptions for the movements of the display. The results of these experiments can be summarised as follows: (i) These naive children appeared to learn little of the way in which time and distance information are separately represented in a journey graph; spatial correspondence was clearly unimportant for promoting such learning. (ii) Children did learn how to relate graphical configurations to sequences of movements by the car. Spatial correspondence had a small effect on learning of this sort. (iii) Learning from passive observation of the display was no different from that following an interaction in which children altered the speed of the car through a remote control. (iv) Children appeared to extract roughly equivalent information from watching the simulation or from reading a sequence of verbal labels indicating (and concurrent with) successive movements of the car.

Our conclusion was that spatio-temporal information in the simulation was not utilised fully in comprehending the journey graph which described its motion. Children did not consider the graph as a time-sampling device plotting the position of the car. However, they readily learned to associate each of the discrete speeds of the simulation with respective gradients of the graph.

Several implications can be drawn from this. The first is that precise and detailed observation of the close spatial and temporal correspondences between simulation and graph does not occur. For instance, the fact that the graph gives positional information about the car at regular intervals of time was not understood. However, the children readily learned that particular motions of the simulation were each associated by temporal contiguity with a specific gradient of the graph. Hence the temporal correspondence of this type of presentation appears to emphasise relations between dynamic states of the simulation and the concurrent behaviour of the graph. This simple kind of associative learning may be aided by the apparent movement of the graph itself. Thirdly, interaction with the display, much vaunted as a desirable attribute of educational programs, had no effect on learning when the duration and content of the displays was strictly controlled. It must be noted that the constraints on interaction were severe in this case, and other factors might be limiting for learning. Nevertheless, our conclusion is that interaction per se (i.e. the potentiality for control) is not always beneficial under restricted conditions of presentation. Advocates of interactive computer programs should now specify the components of interaction which they believe to be beneficial, so that their claims can be tested.

We found these simulation and graph studies interesting, but disappointing from an instructional perspective. Other work using more elaborate simulations in the time, distance and speed domain has also failed to achieve substantial benefits (Gould & Finzer, 1981). It is not the case that presenting more explicit information in the display results in the child appropriately utilising that information.

Our next experiment on graphical representation examined the role of embedded and disembedded contexts. Although our simulation and graph display was concrete and provided explicit spatial and temporal information, it may have lacked any true significance for the child. Donaldson (1978) has argued that children's thinking is best displayed when embedded in a context which has personal and social relevance. Disembedded thinking without such context is more difficult.

To investigate the possible contribution of embeddedness towards understanding journey graphs, we devised a new version of the simulation and graph study (Internal Report No. 7, Publication No. 2). This used traditional materials rather than a computerised presentation (Footnote 3). The display consisted of a street plan with length units (intervals between lamp posts) marked off, and important locations marked. The journeys were described in three ways, which varied the level of embeddedness. (a) In the Embedded (concrete) mode children were told of a boy called Peter, who made a series of journeys across the street plan from his home to particular locations (e.g. the school or the library) marked on the plan. Each of Peter's journeys had a specific purpose, and the details, for example the speed of travel, were given plausible reasons. A paper cutout drawing of Peter was moved over the street plan indicating the journeys. (b) In the Embedded (hypothetical) mode, the same journeys were described, but here children had to imagine the movements for

themselves. (c) The Disembedded mode described the same journeys using point-plotting techniques as in the other conditions, except that here no reference was made to real or imagined journeys of the boy Peter.

In this task children were informed of how graphs are constructed by point-plotting, and there was no opportunity for observation of real-time correspondences between a simulation and graph in an animated display. The object of this exercise was to find out if an embedded context would have a large effect on intitial graphical instruction. If so, then the disembeddedness of the earlier computerised studies might account in part for their failure.

Assistance in carrying out this study was provided by David Dean, an M. Ed. student in the Department of Education at Manchester University. The three teaching procedures were given to matched groups of primary school children. Children were instructed in small groups by the experimenter, and immediately after, were given a written posttest requiring the comprehension and construction of simple journey graphs. The results showed that differences between the three procedures were slight and not statistically significant.

We concluded that embeddedness is not a factor of importance for acquiring understanding of journey graphs. One reason may be that earlier studies emphasising the importance of embeddedness were carried out on younger children (e.g. Hughes, 1981). Embeddedness may not be a crucial factor for older children. Alternatively, tasks with a large visuo-spatial component may be insensitive to the effects of embeddedness. For example, this could occur if the chief difficulty of understanding graphs lies in the coordination of the two dimensions, and if learning this type of relationship through algorithmic procedures such as point-plotting is independent of embeddedness. This conclusion is theoretically unsatisfying. However, the results of this study to some extent free our previous journey graph studies from the criticism that disembeddedness accounts for the lower levels of learning.

We completed another study involving graphical comprehension (Internal Report No. 5, Publication No. 3). In this we examined the influence of the physical system described by the graph on graphical comprehension. Previous studies of graphical comprehension had emphasised this factor (Janvier, 1978; Hart, 1982). Our conceptual framework for this study was that graphical comprehension involves two components. The first we called the spatial syntax of the graph, the graphical features which result from the coordination of two linear orthogonal dimensions. Understanding spatial syntax gives the ability to read coordinate values, estimate slopes, determine maxima and minima, independently of the represented dimensions or physical domain. The second component is the ability to relate the behaviour of the described domain to the features of the graph. Misconceptions may arise at this level by the presence of superficial similarities between the objects of the domain and the appearance of the graph. Both Janvier (1978) and Hart (1982) report errors of this kind. We anticipated further errors

arising from difficulties in relating nonspatial (i.e. temporal) or inverse spatial (e.g. depth) information to a linear, directional axis.

A number of studies have shown difficulties in the comprehension of complex information represented in the form of graphs. However all previous studies known to us were unsystematic, insofar as they varied graphical form in addition to the represented domain. In our investigation, two physical domains were studied. One was the journey graph (in which distance and time were represented on the coordinates), the second was a domain of underground caves, in which the roof height or floor depth below ground were plotted as a function of surface position (distance/distance coordinates). Two multiple-choice questionnaires were constructed, one for each domain, but with identical graphs for each corresponding question. Thus the spatial syntax of corresponding questions was identical but the mapping between domain and graph differed. The questionnaires were administered to over 500 secondary school children covering years 2 through to 5.

The results showed that almost all children, even at the youngest ages, were able to read and plot point values. However, when asked to read maximum and minimum values of the dependent variable, performance was poorer. In the case of journey graphs (but not cave graphs) the commonest error was to select values taken by the dependent variable when the independent variable was at a maximum or a minimum. This misinterpretation may have reflected a tendency to see the graphical line as a road with a beginning and an end in the case of journey graphs. Performance was also poor on cave graphs where depth of the floor (rather than height of the roof) was the dependent variable and thus there was incompatibility between vertical direction in the graph and in the physical domain. In this case, children tended to respond on the basis of the visual appearance of the graph and interpret a rising function in terms of an ascending floor. In both instances the errors arise from directly relating the appearance of the graph and a salient aspect of the physical domain, and failing to interpret the plotted function in terms of the coordinate system.

Before proceeding we should add that it is no simple matter to generate an "equivalent forms" questionnaire of this kind. Some questions which can be asked readily and naturally of one domain are very difficult to phrase when another domain is involved. Indeed, one of the original items in our questionnaires was excluded from analysis for this reason. It may be more realistic to think of graphical comprehension as involving the further level of mapping between a verbal question and the situation or physical domain. However, despite the problem of question construction, we have shown that an important part of the difficulty of graphical problems resides in the mapping between the problem domain and the graphical coordinates.

The major implications for education of our work on Cartesian graphs are as follows: (i) Choice of the physical domain is important: any specific domain will encourage misinterpretation due to superficial similarities between aspects

of the domain and the appearance of the graph. (ii) Disembeddedness or 'unnaturalness' of the instructional context is not a sufficient explanation of children's poor learning under the conditions studied here. (iii) Making explicit the way spatial and temporal information is contained in a journey graph by allowing children to observe an animated microcomputer display is not a sufficient condition for conceptual learning. (iv) Animated displays are effective in promoting simple associative learning by temporal contiguity. (v) Contrary to prevailing views, allowing children interactive control of animated displays does not lead to detectable changes in conceptual understanding. These conclusions do not enable us to make firm recommendations for the use of microcomputers in teaching coordinate graphs. However, they are valuable in ruling out common misconceptions in this area and in helping to specify children's cognitive processes in interpreting graphs - the processes which effective instruction must seek to modify.

(c) Area Estimation by Young Children

The second strand of our research examined children's ability to estimate area, an important example of informal knowledge of physics and also of quantitative ability. Recent theoretical work on the underlying cognitive processes leading to new methods for assessing children's ability (Anderson & Cuneo, 1978; Wilkening, 1979) influenced our choice of topic. These methods appeared to be highly suitable for implementation on microcomputers. We also considered that studying microcomputer-based instruction in these skills would enable us to answer important questions about their acquisition. A short digression is necessary in order to explain the technique used in these studies.

We made use of a new development in psychophysics, known as information integration theory (Anderson, 1974, 1981). Its chief concern is to determine the functional relationship existing between subjective estimates of unidimensional stimuli, such as measures of length or time, and estimates of derived multidimensional quantities, such as area or speed. These functional relationships are believed to reflect cognitive or perceptual operations fundamental for quantification.

The technique used to explore functional relationships is known as functional measurement. This involves collecting subjective ratings for a set of complex stimuli on a suitable rating scale. To ensure an appropriate distribution of ratings, a typical scale will have a large number of intervals (usually 19) and a range limited by the use of end anchors, which are standard stimuli corresponding to the upper and lower limits of the scale. The stimulus set used to collect ratings is well specified. A small number of discriminable stimulus values are chosen for each dimension considered. The stimulus set is made up by factorially combining these stimulus values across the dimensions. In lay terms this means that each stimulus value on dimension A is

combined with each and every stimulus value on dimension B. Ratings are collected for each member of the stimulus set, and usually the stimuli are rated more than once, yielding two or more replications of the data. Figure 2 illustrates the type of display children saw.

As a concrete example, consider the application of functional measurement to the quantification of rectangular area. The two stimulus dimensions here are the width and height. Our later studies, described below, employed three values of width (13, 27 and 40 mm) and the same values were used for height. Combining these factorially thus yields nine stimulus rectangles. These were rated on a scale using an upper end anchor of a large square (52 mm by 52 mm) and a lower end anchor corresponding to zero area. The stimulus set was rated three times, giving three replications of the data.

Information integration theory has several methods for exploring functional relationships. The simplest and most elegant of these involves plotting a graph showing ratings as the dependent variable, with one stimulus dimension plotted on the abscissa and the other as curve parameter. Evidence for the functional relationship between the component stimulus dimensions emerges as response patterns clearly discerned by the shape of the graph. Figure 3 shows some typical response patterns. In Fig 3a, the curves of the graph are parallel, suggesting that the subjective estimates of the component dimensions (width and height) are combined additively to form estimates of the complex quantity (area). We will refer to this as an adding-type or additive response pattern. Another common response pattern shows a divergent graphical form (Fig 3b). This suggests that estimates of the component dimensions are multiplied together to estimate the complex quantity; for area this is the veridical functional relationship. We refer to this as the multiplying response pattern. In addition to these graphical methods, statistical inference can be used to confirm the different patterns of response. In particular, the multiplying pattern of response is identified by a test of the bilinear component of the interaction of height and width in an analysis of variance.

Two interpretations can be placed upon these response patterns. The description above proposes that the complex quantities are estimated by applying a cognitive combination rule to subjective estimates of singular dimensional quantities. An alternative is that these response patterns are perceptual in origin and reflect quantification based on different figural parameters, such as the perimeter (additive response pattern) or the true area (multiplying pattern). The rare convergent pattern (Fig 3c) is likewise interpreted as judgment based on the length of the diagonal. In most of what follows we wish to avoid such interpretation, and we will refer to adding or multiplying strategies of area judgment, distinguished by the patterns of response.

Using these techniques interesting developmental changes in area judgment have been reported by several authors (Anderson & Cuneo, 1978; Cuneo, 1980; Leon, 1982; Verge & Bogartz, 1979; Wilkening, 1979). The basic finding is that young children under

5 years old estimate rectangles inappropriately as an additive function of their height and width (as if estimating the perimeter) whereas older children and adults adopt the correct multiplying strategy. Between these extremes, group data show a gradual shift from the adding to the multiplying strategy with increasing age. This is commonly interpreted as a progressive increase in the number of individuals changing to the more advanced strategy.

One critical assumption here is that the developmental progression reflects changes in the way the stimulus rectangles are perceived and quantified. However, another possibility is that young and older children judge the rectangles in exactly the same way, but differ in the way they express these judgments using the rating scale. Some preliminary experiments (Internal Report No. 6) showed that when rating stimuli that vary on one dimension only, 5 year old and 11 year old children use the 19 point rating scale in very similar ways. Thus we were able to attribute the age related difference to the problem of integrating infromation from two dimensions. Further confirmation of this is provided by Cuneo (1981). Another problem concerns the variability of ratings to individual stimuli. We know that this is much higher for 5 year old than 11 year old children (Anderson & Cuneo, 1978). Under some circumstances this could lead to a misinterpretation of individual or group data. We therefore adopted a cautious and critical approach to the use of functional measurement methodology.

Our first investigations explored the transfer of the area judgment task from the original presentation to a computer-controlled format. Anderson & Cuneo (1978) presented children with rectangles of cardboard (representing biscuits) and used a scale expressed in degrees of happiness. The child's task is to indicate how happy or how sad another (hypothetical) child would be if given each one of the biscuits (test rectangles) to eat. We modified this scenario slightly, referring to the test rectangles as bars of chocolate as in Wilkening's (1979) study. In transferring this task to a microcomputer-controlled format the rating scale was readily adapted. Instead of pointing by finger to a position along a horizontal scale, the child pointed a lightpen at a similar scale displayed on the VDU. However, because of size limitations of the VDU screen the test rectangles and end anchors had to be scaled down from the original investigation.

In the first study (Internal Report No. 4) we found the additive pattern of response in 5 - 6 year old children, replicating the original results of Anderson & Cuneo (1978). But in serious conflict with their results we failed to confirm the multiplying response pattern in either older children (aged 11 years) or even in adults. There were three possible reasons for this: (i) An inherent insensitivity of the microcomputer implementation; for example, difficulty associated with use of a 2-D rather than a 3-D display. (ii) Loss of sensitivity due specifically to reduction in size of the stimulus rectangles. (iii) Choice of inappropriate stimulus values, with insufficient variation to show the bilinear pattern of results indicative of a multiplying strategy.

We thought the third reason was the most likely explanation of our discrepant results, and we investigated this factor by modifying the stimulus set in our next study. (Norman Anderson also suggested this modification in a personal communication). If choice of an unsuitable stimulus set underlies our failure to observe age differences, then this in turn casts some doubt on the conclusions of Anderson & Cuneo. Specifically, their recurrent finding of an apparent additive strategy in young children might have resulted from the insensitivity of their procedure. Conversely, their single reported example of a multiplying response pattern may be a statistical false positive. However, their general conclusions find confirmation in a number of other studies, some of which are more difficult to criticise in these terms (e.g. Wilkening, 1979).

In our second study (Internal Report No. 6) we therefore increased the range of stimulus values. The original study by Anderson & Cuneo (1978) used three values (7, 9, & 11 cm) for width and height, with end-anchor sizes of 5cm and 13 cm squares. Assuming perfect linearity of scaling and perfect judgment of area, the graph of ratings plotted against width with height as curve parameter shows only a small divergence (See Figure 4a). In our modification the rectangles judged for size had sides of length 13, 27 and 40 mm, with an upper end anchor of a 52 mm square, and a lower anchor of zero area. Here, the divergent pattern of the graph corresponding to a multiplying pattern is much clearer (Fig. 4b).

This modified procedure was given to the same children who had previously participated. This time, the group data showed parallelism among the 5 year olds, and a marked bilinear divergence among the older children. A third group of 11 year old children who had not previously been tested showed a marginally significant interaction. The individual data revealed that all of the younger children appeared to be using an additive strategy, whereas about half of the 11 year olds produced divergent graphs indicating use of the correct multiplying strategy for area judgment.

Thus we were able to show that this task, the functional measurement procedure for judgment of rectangular area, could be transferred to a microcomputer-based presentation. The task was easily administered, sensitive to age-related differences, and gave results consistent with other studies carried out with more conventional apparatus. It is unfortunate that considerable time was lost in developing this modified procedure because of unforeseen difficulties.

Although primarily technical and not theoretically motivated, this work does have some educational implications. It shows that judgments of area are made in the same way for two kinds of presentation, one involving the display of real rectangular objects, the other consisting of rectangles drawn to scale. One objection to the use of microcomputers with children is their limitation to pictorial displays. Children may perceive or interpret these differently from tangible objects. Our results overrule this objection, at least for rectangular area judgments. The general question of the equivalence of pictorial and tangible

visual aids is important and should be taken seriously. One consequence of the educational use of microcomputers may be an increase in the extent to which diagrams are used for instructional purposes.

Adapting the functional measurement technique for microcomputer presentation was not a primary aim. Having confirmed that there were qualitative age-related differences in area judgment, educational utility depended on two further demonstrations. First we needed to know if the misconception of area implied by the additive pattern of results was pervasive and so generalised to other tasks demanding knowledge or perception of area. Secondly, we wished to know if the strategies used in area judgment could be influenced by perceptual-motor training. To examine these questions further we embarked on a training study (Internal Report No. 9: Publication No. 4).

This study was conducted on two groups of 8 children, aged 9 -10 years old. One group consisted entirely of children classified as using an adding rule in a functional measurement pretest, whereas the second group consisted entirely of multipliers. Both groups were asked to perform a matching task requiring them to adjust the height of a comparison rectangle until it matched the area of a standard rectangle (of different width). No knowledge of results was given on this area matching task.

Following this each child was given training at area matching involving 15 trials per day for 10 days. Knowledge of results was provided after each match by drawing the correct matching area, and indicating the closeness to a perfect match by auditory tones. Performance on each trial was recorded unobtrusively throughout the training period and stored on the computer. In a post-test, children were again given the area matching task without feedback. Finally, a second functional measurement test was administered to find out if the perceptual-motor training had any influence on area judgment strategies.

Differences between the two groups of children were apparent on the initial area matching test. However, the performance differences did not correspond to the assumption that children classified as adders were basing their judgments on perimeters whereas multipliers were basing theirs on enclosed area. Rather, the adding group showed a greater tendency to match the rectangles for height. This is an example of centration on the manipulated dimension, and has previously been noted in younger children (e.g. Verge & Bogartz, 1978). Thus the strategic differences revealed by functional measurement do not generalise to other tasks involving area estimation.

Analysis of performance during training also failed to show group differences consistent with the functional measurement strategies. We anticipated that the multiplying group would initially perform more accurately, and learn to reduce their errors more quickly. The adding group should be rather slow to learn area matching if they adhered to the wrong stimulus parameters or functional relationships. However, these predictions did not hold. Although errors decreased significantly

with training, there were no clear group differences in mean area matching errors either during training or in the area matching posttest.

Together, these results suggest that the qualitative differences in area judgment assessed by functional measurement do not reflect pervasive misconceptions of area which are carried over to other related tasks. A more surprising result was that the functional measurement posttest was inconsistent with the pretest. Whether classified as adders or multipliers, about half the children exhibited a different strategy on the post-test. This raises doubts about the stability of the area judgment strategies. It might be the case that the training procedure encouraged children to vary these strategies. Alternatively, within this age group, there might be considerable spontaneous fluctuations in the strategies adopted on different occasions, as if the rules were selected from a number of possible alternatives at the time of test (Wilkinson, 1982).

Our final study of area judgment used a test/retest paradigm to observe if changes of strategy occurred spontaneously (Internal Report No. 8; Publication No. 4). Over 60 children were tested using our standard functional measurement procedure, and were given an unexpected retest some 4 - 5 weeks later. The results showed that roughly half (46 %) the children who could be classified with certainty according to standard functional measurement strategies, showed evidence of using different strategies on the test and the retest. Careful examination of the data showed that these changes were not due to unreliability of the testing procedure, but originated from real, and apparently spontaneous variations in performance.

Our initial position in undertaking this kind of study was that children's intuitive knowledge was (a) erroneous, at least in some individuals, (b) consistent across a variety of tasks within a subject domain, (c) manipulable by training and (d) possibly responsible for misconceptions arising in formal knowledge. It seems that we were mistaken with respect to points (b) and (c). Among older primary school children the procedures children use to estimate area fluctuate over time, and are not consistent across tasks. Other studies (e.g. Leon, 1982) suggest that the judgmental procedures children adopt can be influenced by the immediate context, and are therefore situation-specific.

These results on area judgment carry the implication that visual aids as simple as rectangles may be misinterpreted, at least by primary school children. Further, the type of misinterpretation may vary from one occasion to the next. To consider a simple example, if rectangular outlines are used to illustrate problems involving the comparison of areas, then there may be conflict between the illustration and the result of an accompanying numerical computation, depending on whether an adding (perimeter) or multiplying rule is used to interpret the diagrams. Teachers should be aware of this. It is possible that such confusion can be avoided by the use of simple procedures, orienting children towards the correct strategy each time such illustrations are used. Superposition or subdivision examples might suffice, but unfortunately we did not have time to take up

the investigation of these issues.

(d) Lightpen Interaction.

Between these two main areas of research, we examined one simple problem in child-machine interaction (Internal Report No. 3; Publication No. 5). We wished to know if the lightpen was a suitable device for children to use in conjunction with a microcomputer-controlled display. The chief advantage of lightpen interaction is that it requires only the natural response of pointing at a target, with the requirement that it be held there long enough for the target to be determined. No intermediate representation is required, as in situations where numbered alternatives are selected. However, there was some uncertainty concerning lightpen use with very young children, because of their perceptual-motor limitations. To investigate this problem we designed a computer-controlled display which allowed us to measure the accuracy of placing the lightpen over a target and then, by taking successive readings, the child's ability to hold a constant position for a short period of time.

The results showed that 5 year olds were able to use the lightpen, but they showed significantly larger errors in initial placement than 11 year olds. They also had greater difficulty in holding the lightpen steady. From these data, we were able to make some quantitative recommendations for the design of lightpen interactive displays. Informal observations revealed that the younger children suffered from considerable muscular fatigue: when working at normal reading distance, these small children could only point to targets with an unsupported arm. Also, some parallax errors in aiming were observed in both age groups, and these were not spontaneously corrected.

OBSERVATIONS AND RECOMMENDATIONS

(a) Organisation of the Project.

Many difficulties were encountered in running this project. Although not central to this report, we comment on some of them here in the hope that others might profit from our experience.

First, in terms of manpower, our organisation was rather top heavy. It was useful to have a wide range of expert knowledge on which to draw, but bottlenecks occurred at the level of running and executing experiments, rather than at planning and theoretical stages. With hindsight a better arrangement would be to employ two full-time research assistants, one of whom would be dedicated to programming, the other to running experiments and writing them up. A single appointment at research associate level to cover these duties is perhaps not optimal use of resources.

Programming was only one of two very time consuming overheads. Much time was also spent preparing the internal reports and articles for publication. There was provision for some secretarial assistance within the project, but this was not enough to cover the laborious typing and preparation of these

documents. More secretarial assistance, up to a limit of 2 days per week would have been helpful.

A more pressing problem in the early stages was getting hold of essential equipment. No provision for the purchase of equipment could be made within the standard conditions attached to the grant award. Fortunately, throughout the first few months of the project we had the use of an Apple II microcomputer on loan from the Department of Psychology at Manchester University. Several appeals were made to hardware manufacturers, but although promises were made, none were fulfilled. Eventually the project obtained its own Apple II through the University of Manchester Special Equipment Fund.

The use of a machine dedicated to the project was essential and progress would have been severely impaired if we had not obtained one. We regard it as a serious criticism that in order to undertake research of this kind, the acquisition of essential equipment is dependent on goodwill. In an economic climate that is currently harsh, and seems likely to remain so, reliance on such sources for essential equipment may jeopardise progress.

Access to schools for experimental purposes was not a problem for this project, but difficulties could arise in future. Generally, it is much easier to operate in primary than in secondary schools, which suffer from an overcrowded timetable. This factor influenced us in our decision to work mainly with primary school children. Even so, we were on occasion turned away from local primary schools who considered that too many demands were being made by local researchers and student teachers. There may be a case here for some coordination between research and educational institutions on the one hand, and the local education authority on the other. However, the experience of other investigators suggests that this can cut both ways, as security of access is gained at the cost of extra administration and consequent delays.

(b) Educational Research

The new educational technology has brought with it a number of claims and prescriptions for the efficacy of innovative instructional techniques. From what we have seen in the literature, and from our own experiences, we believe many of these claims to be unfounded. For example, evaluations of the cognitive benefits of programming in young children are largely absent (but see Howe et al., 1982). enterprises have been headline news for several years.

An example from our own project concerns the general enthusiasm for interactive computer programs.While it is true that interactive visual aids are a recent development, and may have special advantages, it would be prudent to determine quantitatively what these advantages and benefits are, and also the boundary conditions within which they occur, so that the relevant features can be understood, and perhaps improved upon. The tendency we criticise here for making claims in the absence of such evidence may be expensive, since in truth the new

technology may not have advantages over the old. A recent survey of new educational developments in the United States, (Sage and Smith, 1983) has also expressed regret at the inadequate attempts made to evaluate new techniques. These comments are particularly applicable to cognitive aspects of educational innovation.

Apart from the specific use of microcomputers as instructional devices there are other considerations. For example, the introduction of microcomputers into schools may result in changes in pupils' motivation. This issue is worthy of some attention. Typically, classroom enthusiasm for the new technology is mentioned as an unquantified gloss (alas in some of our reports as well as elsewhere) . Given that any experimental procedure in a school environment will call up a Hawthorne effect, and that new technology arouses children's enthusiasm and curiosity, it would be surprising if motivational surges did not arise in educational experiments of this kind. Many of the observed benefits could be due to this factor alone. Obviously, such confounding motivational effects are inevitably present when comparing new and old educational methods. The cognitive approach can be useful here, since (i) it involves close experimental control and (ii) it looks for demonstrable variations in the organisation of knowledge which result from instruction.

Despite these advantages of a cognitive approach to the investigation of educational problems, and its proven utility in some subject areas, there is at present no centre in the UK devoted to research in the cognitive psychology of instruction.

References

Anderson, N. H. Algebraic models in perception. In E.C. Carterette & M. P. Friedman (Eds.) Handbook of Perception (Vol 2). New York: Academic Press, 1974.

Anderson, N. H. Foundations of information integration theory. New York: Academic Press, 1981.

Anderson, N. H. & Cuneo, D. O. The Height + Width rule in children's judgments of quantity. Journal of Experimental Psychology: General, 1978, 107, 335-378.

Carpenter, T.P., Moser, J.M. & Romberg, T.A. (Eds.) Addition and subtraction: A cognitive perspective. Hillsdale, N.J.: Lawrence Erlbaum, 1982.

Cuneo, D. O. A general strategy for judgments of quantity: The height + width rule. Child Development, 1980, 51, 299-301.

Cuneo, D. O. Children's judgment of numerical quantity: A new view of early quantification. Cognitive Psychology, 1982, 14, 13-44.

Donaldson, M. Children's Minds. Glasgow: Fontana/Collins, 1978.

Frith, U. (Ed.) Cognitive processes in spelling. New York: Academic Press, 1980.

Gould, L. & Finzer, W. A study of TRIP: A computer system for animating time-rate-distance problems. In R. Lewis & D. Tagg (Eds.) Computers in Education North Holland Publishing Company, 1981.

Hart, K. (Ed.) Children's understanding of mathematics: 11-16. London: John Murray, 1980.

Howe, J. A. M., Johnson, K.R., Plane, S. Inglis, R. Teaching mathematics through programming in the classroom. Computers and Education, 1982, 6, 85-91.

Hughes, M. Can preschool children add and subtract? Educational Psychology, 1981, 1, 207-219.

Janvier, C. The interpretation of complex Cartesian Graphs representing situations -- studies and teaching experiment. Unpublished PhD Dissertation, University of Nottingham, 1978.

Leon, M. Extent, multiplying and proportionality rules in children's judgments of area. Journal of Experimental Child Psychology, 1982, 33, 124-141.

Lesgold, A.M. & Perfetti, C.A. (Eds.) Interactive processes in reading. Hillsdale, N.J.: Lawrence Erlbaum, 1981.

Papert, S. Mindstorms. Brighton, Sussex: Harvester Press, 1980.

Phillips, R.J. An investigation of the microcomputer as a mathematics teaching aid. Computers and Education, 1982, 6, 45-52.

Sage, M. W. & Smith, D. J. Microcomputers in education: A framework for research. SSRC Report, HMSO, 1983.

Verge, C. G. & Bogartz, R. S. A functional measurement analysis for the development of dimensional coordination in children. Journal of Experimental Child Psychology, 1978, 25, 337-353.

Wilkening, F. Combining of stimulus dimensions in children's and adults' judgments of area: an information integration analysis. Developmental Psychology, 1979, 15, 25-33.

Wilkinson, A. C. Partial knowledge and self-correction: Developmental studies of a quantitative concept. Developmental Psychology, 1982, 18, 876-893.

FOOTNOTES

(1) We are extremely grateful to the following: Mrs. Anne Rainford for secretarial assistance, especially in the printing and preparation of these internal reports, also to Elaine Baker, Erica Burman, David Dean, Peter Gay and Kevin Silber for excellent assistance in carrying out various experiments.

(2) Another unique facility of educational computers lies in programming. Some claims made for the cognitive benefits of learning to program early in life have been made (e.g. Papert, 1980), but as yet these claims have been inadequately assessed, and intrinsically they are very hard to test. We decided at an early stage not to follow this avenue of enquiry.

(3) This study was run concurrently with other experimental work. Consequently no resources were available to adapt the animated concurrent simulation and graph program for use in this experiment.

INTERNAL REPORTS.

(1) Avons, S. E., Beveridge, M. C., Hickman, A. T. & Hitch, G. J. Teaching journey graphs by microcomputer animation: Effects of spatial correspondence and degree of interaction. (July, 1981)

(2) Avons, S. E., Beveridge, M. C., Hickman, A. T. & Hitch, G. J. Teaching journey graphs by microcomputer animation: contributions of a concurrent visible simulation and verbal speed labels. (August, 1981)

(3) Avons, S. E., Beveridge, M. C., Hickman, A. T. & Hitch, G. J. The lightpen in interactive raster graphics: Design considerations, measurement of characteristics and the handling capability of young children. (April, 1982)

(4) Avons, S. E., Hitch, G. J., Beveridge, M. C. & Hickman, A. T. Information integration theory and the development of area judgment: a microcomputer implementation. (May, 1982)

(5) Hitch, G. J., Beveridge, M. C., Avons, S. E. & Hickman, A. T. Effects of reference domain in children's comprehension of coordinate graphs. (May, 1982)

(6) Avons, S. E., Hitch, G. J., Beveridge, M. C. & Hickman, A. T. Area and length estimation in primary school children. (August, 1982)

(7) Beveridge, M. C., Dean, D. J., Avons, S. E. & Hitch, G. J. Teaching journey graphs to primary school children: a comparison of procedures.

(8) Avons, S. E., Hitch, G. J. & Beveridge, M. C. Reliability of area judgment: A test/retest study. (May, 1983)

(9) Avons, S. E., Hitch, G. J. & Beveridge, M. C. The effect of training on area matching and size estimation in children. (June, 1983)

PUBLICATIONS OF THE MICROPROCESSORS IN EDUCATION RESEARCH PROJECT

(1) Avons, S.E., Beveridge, M.C., Hickman, A.T. & Hitch, G.J. Teaching journey graphs with microcomputer animation. Human Learning, 1983, 2, 93-105.

(2) Beveridge, M. C., Dean, D. J., Avons, S. E. & Hitch, G. J. Teaching journey graphs to primary school children: a comparison of procedures. Educational Psychology, 1983, 3, 149-159.

(3) Hitch, G. J., Beveridge, M. C., Avons, S. E. & Hickman, A. T. Effects of reference domain in children's comprehension of coordinate graphs. In D. Rogers and J. Sloboda (Eds.) Acquisition of Symbolic Skills. New York: Plenum, in press.

(4) Avons, S. E., Hitch, G. J. & Beveridge, M. C. Stability and pervasiveness of children's area judgment strategies. Submitted for publication to the Journal of Experimental Child Psychology.

(5) Avons, S. E., Beveridge, M. C., Hickman, A. T. & Hitch, G. J. Considerations on using a lightpen-interactive system with young children. Behavior Research Methods & Instrumentation, 1983, 15, 75-78.

OTHER COMMUNICATIONS

Beveridge, M. C. Research on educational microcomputers in Manchester. Primary Contact, 1983.

Beveridge, M.C., Avons, S.E., Hickman, A.T. & Hitch, G.J. Teaching journey graphs using microcomputer animation. Paper presented at British Psychological Society Developmental Section Conference, Manchester, 1981.

Hitch, G.J., Beveridge, M.C., Avons, S.E. & Hickman, A.T. Effects of reference domain in children's comprehension of coordinate graphs. Paper presented at NATO International Conference on the Acquisition of Symbolic Skills, Keele, 1982.

Beveridge, M.C., Avons, S.E. & Hitch, G.J. Microcomputers versus traditional teaching procedures: A comparison of approaches to the teaching of graphs. Paper presented at British Psychological Society Education Section Conference, Durham, 1982.

Dean, D.C. Teaching journey graphs to 10 and 11 year olds: A comparison of procedures. Paper presented at meeting of the British Society for the Psychology of Learning Mathematics, Open University, 1983.

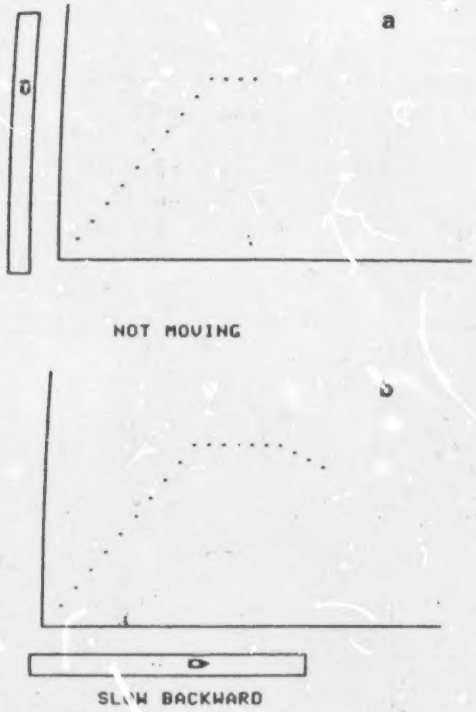

Figure 1. (a) Arrangement of the simulation and graph in the 'vertical' conditions, showing direct spatial correspondence between the position of the car and the graph. (b) Arrangement of the simulation and graph in the 'horizontal' conditions, showing a later stage in the same journey. Note that the relation of the simulation to the graph is obscured in this case.

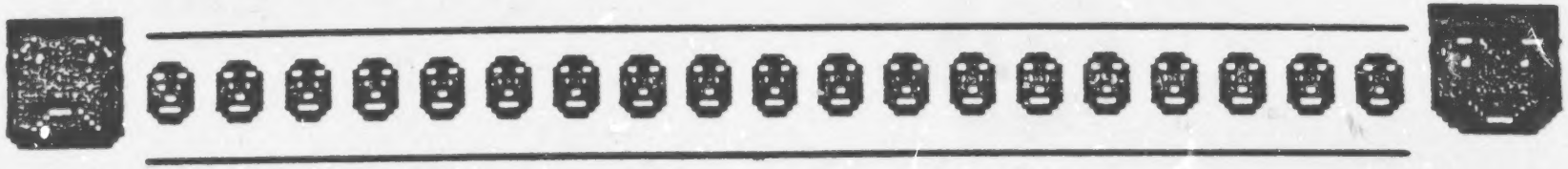

Fig. 2

Fig 3 Response Patterns of Area Judgment.

Width plotted on abscissa
Height as curve parameter: X = height 1
⊙ = height 2
△ = height 3

Fig 3 (a)
Additive Pattern

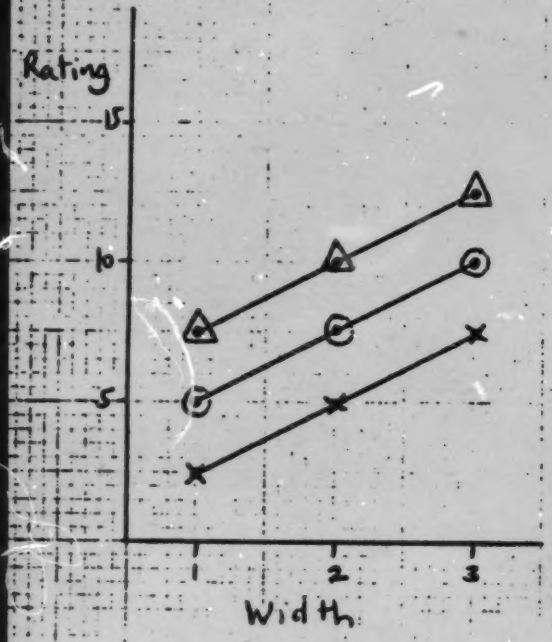

Fig 3 (b)
Multiplying Pattern
(Divergent Fan)

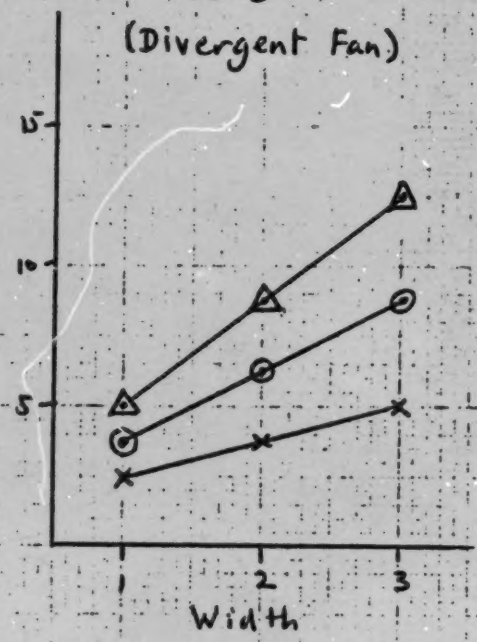

Fig 3 (c)
Convergent Pattern.

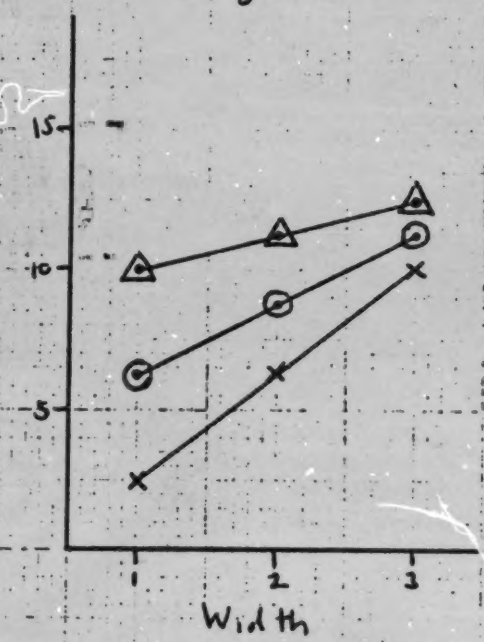

Figure 4a

Linear Scale Ratings of Computed Stimulus Areas

(previous study)

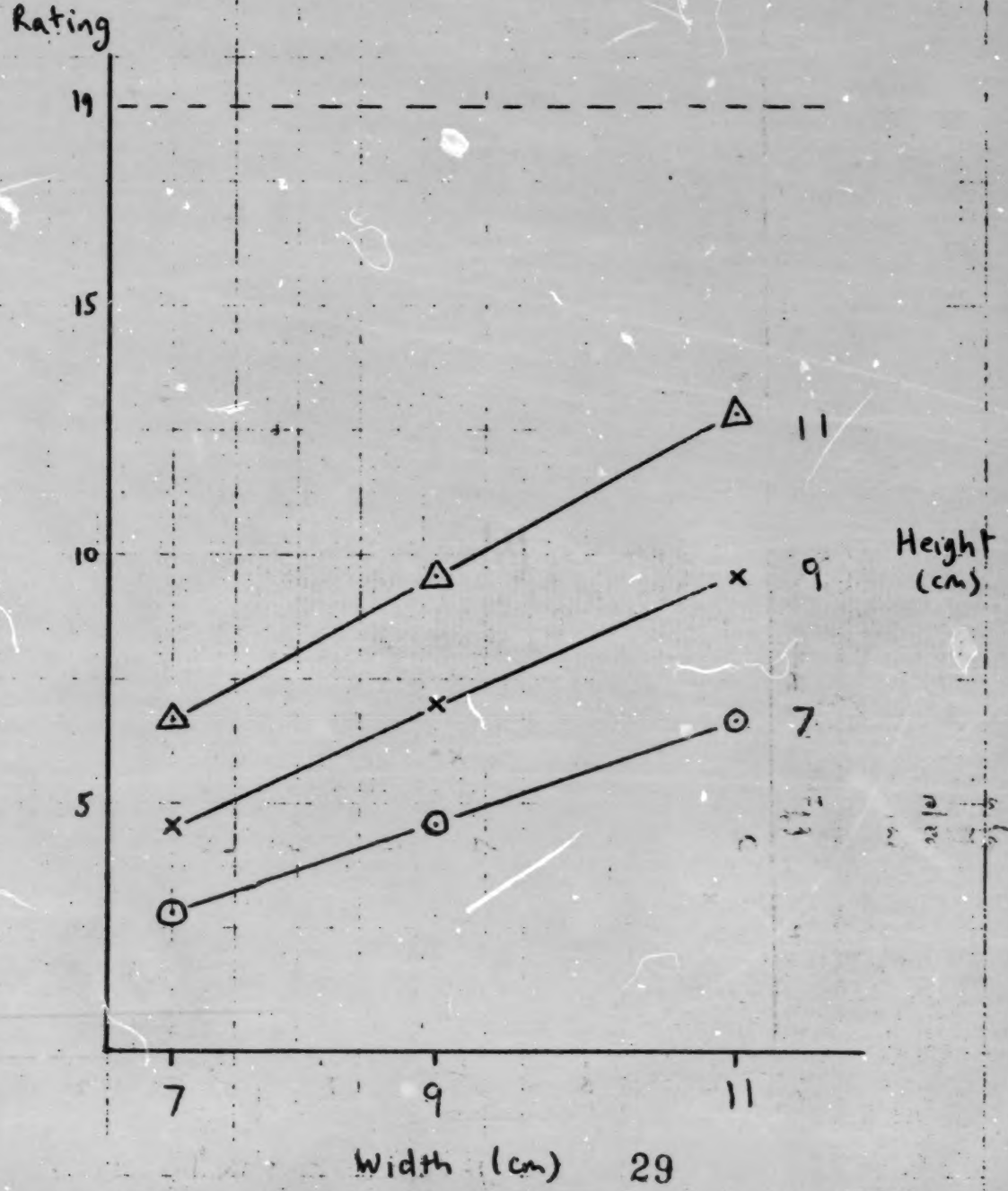

Figure 4b

Linear Scale Ratings of Computed Stimulus Areas (current study)